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The Stanford Center for Radar Astronomy is a joint venture of groups at Stanford University and SRI who share an interest in the application of radar and other radio techniques to a broad range of problems. We are concerned with the scientific study of our planet and the whole of the solar system, and with technological and other developments for improved communications and related national space-application programs. This work is conducted with support from NASA and other federal agencies and involves graduate student research assistants working toward advanced degrees. Studies involving the propagation of radio waves between ground terminals and a probe in space (bistatic radar astronomy) have received special emphasis. This technique has been successfully applied to studies of the earth's ionosphere, the cislunar medium, the interplanetary medium, the solar corona, the atmospheres of Mars and Venus, and the surface of the moon. Members of the staff of the Center have been or are involved in radio science experiments on Pioneer, Explorer, Lunar Orbiter, Apollo, and Viking spacecraft, and on Mariner missions to Mars, Venus, Mercury-Venus, and Jupiter-Saturn.

The complex nature of radio and radar experiments and development requires expertise in a variety of subject areas. For example, bistatic-radar experiments conducted with space probes require a familiarity with orbital mechanics, optimal signal detection theory, numerical analysis, spacecraft instrumentation, and electromagnetic propagation and scattering theory. In addition, all relevant information on the region of study (such as the rings of Saturn) obtained from other sources must be understood in the context of what the radar or radio investigation can contribute. Equally diverse disciplines are required for the other

experimental, theoretical, and applications areas mentioned above. As a result the Center is made up of individuals of highly varied backgrounds and specialized abilities, and graduate students working toward dissertations on a broad range of subjects. However, the unifying principal underlying all the work of the Center has been, and remains, research into physical phenomena of the space and planetary environments, and other related applications of the techniques of radio science and technology.

The Center has been supported by both grant and contract sources. Projects, such as the Pioneer 6-9 or Apollo 14-16 experiments, have been carried out on a contract basis, following the acceptance of the experiment by the sponsoring agency (usually NASA). Some grants for definite purposes have also been obtained, and both grants and contracts have been awarded for individuals in the Center to participate in the mission definition and implementation phases of the radio teams chosen for planetary missions. However, the NASA sustaining grant has provided the fundamental nucleus from which other work has evolved.

At the Center, the sustaining grant (NGL 05-020-014) covers a broad spectrum of activity in space sciences. During the past year the grant has been used for support in three general areas. (1) Theoretical and experimental efforts of certain graduate student research assistants and staff members are supported by the grant, in a number of areas of space science or applications which may not have specific connections with any NASA flight project. (2) The efforts of some members of the Center are supported, at least in part from the grant, in areas which are either expected to develop into future separate projects, or which are peripheral to the main thrust of other present projects (such as a separately-funded

flight project), but which, nevertheless, show promise for possible future developments in that field. (3) Of vital importance to the activities of the Stanford Center for Radar Astronomy is the role of the grant in providing continuity and the ability to respond quickly to new opportunities, and in helping to provide for support equipment and support capabilities for the benefit of all of the activities of the Center.

In the following pages, individual staff and student contributions in Section A outline current research activities at the Center. Section B lists, Recent Publications, Technical and Scientific Reports and Symposia attended and Papers presented.

SECTION A

Faculty, Staff, and Student Contributions

Thomas A. Croft

Studies of Refraction, Scintillation and Retardation Effects

A number of projects have been undertaken relating to the inner planets, the outer planets, and to the sun itself. Underlying all these diverse regions for study is the common aspect that in each case, the observational methods employed or proposed depend on the refraction, scintillation or retardation of radio signals which are both generated and received by man-made devices. It might also be said that each study is based upon radio signal modifications due to the atmosphere of a heavenly body, if one is willing to consider the solar wind as being the atmosphere of the sun.

A range of atmospheres of the planet Venus was used as a basis for constructing models of the refractivity distribution; these were used in turn as a basis for digital computer ray tracing. Such studies had previously been conducted as part of a small-scale effort to determine if the ashen light of Venus could be explained on the basis of super-refraction from the bright side to the dark side followed by scattering toward earth. During this reporting period, the work was carried further in an effort to provide advice to NASA/Ames concerning the design constraints of the multiprobe mission, Pioneer-Venus 1977. Some occultation studies were also performed, yielding interesting comparisons between the effects of certain atmospheric anomalies on lander radio signals as compared to orbiter radio signals. It is expected that this work will be continued with an emphasis on increasing the realism of the simulation and, possibly, upon including horizontal gradients of refractivity to see if detectable and/or deleterious signal changes might be detected, as a result.

Together with Drs. Eshleman and Tyler, Dr. Croft became a member of the Radio Science Team for the Mariner Jupiter/Saturn 1977 mission. The S-X dual-frequency radio system may permit the monitoring of the interplanetary medium during the long cruise phase of this mission, possibly including measurements out of the ecliptic plane after the Saturn encounter. The operation of such an experiment is expected to run a close parallel to the existing (but lower-frequency) experiment which has been run by this Center on five spacecraft during a sequence which began in 1965 and continues to this day. The same radio system will provide a good deal of information about the atmospheres of Jupiter, Saturn, Titan and perhaps other minor planets by virtue of the refraction, retardation and scintillation of the signals. Our calculations of the range of expected radio performance patterns will play a part in determining the hardware, software and orbit selection for this pioneering venture beyond Jupiter.

Interplanetary scintillation studies are well under way, taking advantage of the unique data obtained by Pioneer 9 when it went behind the sun in late 1970 and emerged in early 1971. During this period, heavy scintillation was observed on our 50 and 423 MHz signals and, at the same time, 2200 MHZ tracking and telemetry signals were also scintillating. This triple-frequency observation of CW sources during occultation by the sun is not only unique among all past space experiments, but also it appears to be unmatched by any future spacecraft under consideration. The fact that the signals are known to originate as continuous wave point sources eliminates some of the ambiguity associated with the observation of scintillating radio stars which orignate as noise from a region of finite angular extent.

The technical problems involved in recovering these data from the telemetry records were not trivial and have only recently been carried to the stage where the final form of the data could be analyzed. We have now reached the stage where we can calculate scintillation indices and begin the process of correlating the character of these observations of the solar wind with other parameters. One of the other great advantages of this scintillation measurement is that it was accompanied by a measurement of the solar wind electron content. The scintillation indicates the variability of the content so that the actual measurement of the content permits a calculation of the percentage variation, an important parameter usually derived in past scintillation studies on the basis of an estimated content for some typical, spherically symmetric, static, solar-wind model. We know from the measurements of the content that the day-to-day variations can be extreme.

Interplanetary content measurements continue, making use primarily of Pioneers 8 and 9. For a short time during the reporting period, Pioneer 6 completed its first circuit of the sun and returned within operating range. For a few months we obtained many measurements with this spacecraft which has endured more than 12 times longer than its design lifetime.

In early August there was a great deal of unusual activity near earth which fortunately coincided with the alignment of Pioneers 9 and 10 along the same heliocentric radial. Because it was expected that Pioneer 9 would monitor the solar wind later expected to envelop Pioneer 10, the Deep Space Network operated Pioneer 9 at unusually frequent intervals during the first two weeks of August, 1972. When the large plasma outbursts of August 3 and 9 occurred, we were consequently in a state of readiness and operated

almost every day for the period before, during, and after the anomalous behavior. This has yielded excellent diagnostic clues bearing on the distribution of electrons. Our results have been reported in the AGU and a letter on the subject has been accepted by the Journal of Geophysical Research. The study of this event is continuing as is the study of many other aspects of solar wind electron content measurements taken by Mariner 5 and Pioneers 6, 7, 8 and 9.

Horen Chang

Interplanetary Scintillations

The study of the fluctuations of radio signal strength caused by irregularities in the solar wind provides a valuable tool for probing the interplanetary medium. Staring in November 1968, a series of interplanetary scintillation recordings have been made at Stanford. By simultaneously transmitting two constant-amplitude signals, 49.8 and 423.3 MHz, along a radio path from Stanford to Pioneer 9, the received signal power levels (or the so-called "format D data") showed rapid fluctuations; furthermore, the ratio of maximum-to-minimum received signal power was extremely large ($\approx$15 dB) when the radio path passed through or near the solar outer corona.

Strictly speaking, the format D data is not a measure of signal power level but a measure of signal-to-noise power ratio. The received noise in interplanetary space consists mainly of three parts: (1) receiver noise, (2) solar noise, and (3) cosmic noise. Since the solar and the cosmic noise are not isotropic, and Pioneer 9 spins approximately once per second, the received noise is thus anisotropic. Detailed calculations, nevertheless, indicated that the received noise is essentially isotropic within the error range of 0.3 dB, which is almost negligible compared with 15 dB

strong scintillations. With tolerable accuracy, therefore, the format D data may be regarded as a measure proportional to the signal power level only. This assumption also served to simplify our primary task on data reduction.

Subtracting the antenna patterns from all the digitally recorded format D outputs to get the clean scintillation data, we have finally processed sufficient data to begin the interesting phase of the study. The interpretation of the observations, of course, rests on an adequate model of the propagation of electromagnetic waves through the turbulent solar wind. Until recently, the so-called "Gaussian thin phase-diffracting screen" model has been used with considerable success in estimating the scale and the velocity of the turbulence. Nevertheless, Young (1971), argued that the Gaussian phase-screen model is not appropriate and proposed a power-law model for a spherically-symmetric solar wind. Also, Jokipii and Lee (1972) derived a scintillation equation by using Young's power-law model. Armstrong et al.(1971), however, claimed that the probability distribution of their observed scintillation intensities could not be explained by Young's theory. Other arguments exist but it must be noted that almost all interplanetary scintillation studies have been based on observations of radio stars, which are unknown, extended, noisy sources at infinity. In contrast, as pointed out by Croft (1970), we have obtained our signals from spacecraft for which the ground station serves as an ideal point source transmitting constant-amplitude waves so that all fluctuations are known to be caused by inhomogeneities in the intervening plasma. Besides, ours is also the only measuring system ever occulted by the sun while making simultaneous electron content and radio signal amplitude measurements. It is thus hoped that

our study will contribute valuable experimental evidence on interplanetary scintillation theories and increase our knowledge about the turbulence of the solar wind.

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H. T. Howard

The Bistatic Radar Program

The experimental and data reduction phases of the Apollo Bistatic Radar program are now nearly completed at the Center. Data collected simultaneously at 116 cm and 13 cm wavelengths from Apollos 14, 15 and 16 have been reduced to their final form for submission to the NSSDC. The data package will be documented in such a way that other experimenters can have rapid and easy access to meaningful experimental results. Several papers have been published and two more are in press.

The polarized parts of the echo spectra are reduced according to the theory of quasi-specular scattering from a gently undulating surface while the unpolarized portions are associated with a diffuse scattering mechanism. When adjusted to normal incidence, the ratio of polarized to unpolarized power is 8(+1, -3)db at the 13 cm wavelength. Variations in the 13 cm unpolarized power are on the order of 1 db. At 116 cm, variations in the ratio of polarized to unpolarized power are considerably

larger, on the order of 5 db. In two regions, near Lalande δ and the northern portions of Hipparchus, the unpolarized power apparently exceeds the polarized power. The craters Lansberg, Bessel, and Euler are not detectable in their effects on the orientation and eccentricity of the polarization ellipse or on the unpolarized component. Within Mare Serenitatus and Oceanus Procellarum the 13 cm data follow a classical Fresnel reflection curve corresponding to relative dielectric constant $\epsilon = 3.1 \pm .1$. Over most of these same areas, the 116 cm data are consistent with this value of relative dielectric constant. However, in some areas, notably between Reiner and Hevelius, there are marked deviations from the reflectivities predicted for $\epsilon = 3.1$. These results cannot be explained on the basis of simple models employing contiguous, semi-infinite, dielectric interfaces. In the highlands to the south and southwest of Mare Crisium the relative dielectric constant obtained at 116 cm wavelength is $\epsilon = 2.8 \pm .1$. In this region, the 13 cm data depart from the reflectivities predicted for a simple dielectric interface. These departures may be explained in terms of models employing layered dielectric structures. In Oceanus Procellarum, a model which has a local minimum in density at a depth of 2 to 4 m is consistent with the data. Lunar rms slopes, as determined by the gaussian equivalent method from the polarized frequency spectra, show systematic differences with respect to mare and highlands units. Within the highlands, the rms slopes obtained at the two wavelengths are nearly equal and vary between tan 6° and tan 8°. Within mare units, rms slopes inferred from the 116 cm data vary between tan 1° and tan 2°. Mare rms slopes at 13 cm are in the range of tan 2° to tan 4°. At the same location, the slopes obtained at the 116 cm wavelengths are typically one-half as large as those obtained

at 13 cm. Using Hagfors' (1966) model for wavelength dependence, we conclude that on a 0.2 to 2 m surface scale the mare are rougher than the the highlands, albeit overall on larger scales the opposite is the case.

Funding for the program expires in June though analysis is expected to continue under a separate Headquarters grant. The AFO for such investigations is expected early in CY 73. Analysis of the data has produced a number of clear results and shown the direction for future work.

Essam Marouf

Radar Studies of Planetary Atmospheres

Spherically-symmetric models of planetary atmospheres are usually used to study the average effects on a radar signal that has probed the atmosphere. Such models, however, do not account for the stochastic fluctuations of amplitude and phase usually observed in the received signal. Both the receiver noise and the random variations in the refractive index of the medium (spatial and/or temporal) are usually the cause of the random variations in the parameters of the received signal. Models that take into account the stochastic part of the refractive index variation are under study for the cases of a fly-by probe (or an orbiter) as well as for an entry probe. The aim is to relate the assumed stochastic model to the expected variations in the received signal and then to determine the optimum receivers for the detection and estimation of signal parameters.

Propagation to a spacecraft occulted by the rings of Saturn is also under study. Existing models of the rings based on spectroscopic, photometric, and stability studies indicate that the rings are most probably

a system of many bodies, each body moving in very nearly circular orbit with Keplerian velocity and oscillating normally to the plane of orbit with relatively smaller random velocity.

The sizes of the individual bodies, their material and surface roughness, their volume density, and their radial distribution are still open questions and more study is needed to obtain more informative results. The effect of different models on the probing radar signal is being analyzed. The analysis also considers the inversion problem, that is, the reconstruction of reasonable models based on the measured effects on the probing radar signal.

Faruq Ahmad

Analysis of Ionospheric Scintillation

The ATS (Applications Technology Satellite) is a satellite in synchronous orbit around the earth, sending back a 136 MHz linearly-polarized signal. Information provided by ATS has been used in ionospheric studies; for instance, the signal rotation has been used to estimate the electron content of the ionosphere.

I undertook the analysis of data which had been obtained in April 1972 from ATS. The data I dealt with consisted of the variation with time of the orientation of the polarization ellipse of the signal. These polarization-angle data were superimposed on a low-frequency trend, the consequence of long-term ionospheric variations. This trend was first subtracted by fitting polynomials to it, and the zero-average data which resulted was Fourier-transformed to obtain its frequency spectrum, and subsequently its power spectrum. Most of the power was seen to be

contained at frequencies readily identified as being those involved in data transmission; these were therefore filtered out. The variance of the data both before and after filtering was calculated from the rms values.

Since the actual signal/noise ratio for the transmission was known, the next step was to predict from this value the allowable data variance for the noise levels which were present. If the actual variance were larger, then information not explained by noise levels would be present. Toward this end, the signal was modelled as a phasor with Rayleigh noise. For the valid approximation of high signal/noise ratio, the expected signal variance vs signal/noise ratio was plotted for this model. The actual ATS polarization angle data variance value previously calculated was then used to read off predicted signal/noise ratios. These were discovered to be close to the actual signal/noise values; it was hence concluded that the noise level present could fully account for the power spectrum obtained and the analysis was terminated. A report is presently being written on the analysis.

In late 1972, bistatic geometry experiments were conducted in the Hawaiian Islands, using primarily the Loran-A Transmitter. The interpretation of the results involves modelling the attenuating effect of the islands on signals being transmitted over them. I am presently in the process of determining such a model. Initial results indicate that in the case where high altitude peaks exist between transmitter and receiver, their attenuating effect can be well approximated by modelling them as 'knife-edges'. This simple model breaks down when distances between transmitter and receiver are increased and the intervening land is relatively flat. Under such conditions, the dielectric properties of the land surfaces have to be considered as well in any estimation of the attenuation.

Michael Frankel
John Vesecky

Magnetospheric Radio Noise Emission Processes

Observations of radio noise from the magnetosphere are now being made regularly from RAE-1 and IMP-6. The IMP-6 observations are characterized by a continuum component below about 100 kHz and a burst component between about 100 and 700 kHz. The research objective is to explain these two characteristic types of emission in terms of known magnetospheric particle populations.

Satellite observations over more than a decade have defined magnetospheric particle populations and their variations to a substantial degree. Likewise a number of radio wave emission processes are well known. We therefore intend to examine the many possible combination of particles and emission mechanisms to find which ones can explain the present IMP-6 observations and which ones might be discovered by appropriate observations. Table I gives a preliminary listing of the combinations which seem the most promising.

The radiation mechanisms mentioned in this Table are relatively well described as follows: synchrotron radiation, Liemohn (1965), Vesecky (1967), Pachokzyk (1970); Cerenkov, Liemohn (1965); cyclotron-resonance wave amplification, Kennel and Petschek (1966), Brice and Lucas (1970). In most cases a rather straightforward application of existing radiation theory will be sufficient. However in cases involving radiation near the electron plasma and gyro-frequencies, the synchrotron theory is somewhat incomplete and some literature searching will be necessary. In this and

TABLE I

Potential Magnetospheric Radiation Processes

DATA SOURCE	PARTICLES TYPE	PARTICLES ENERGY	REGION	TIME	MECHANISM	E-M RADIATION
OGO-5	Stably trapped	50 keV-5 MeV	$L \leq 8$	Substorm	Synchrotron	10 kHz-10 MHz
OGO-5	Stably trapped	50 keV-5 MeV	"Horns" of outer belt	Quiet and disturbed	Synchrotron	100 kHz-10 MHz
IMP-4 and 5 OGO-5 OV series	Interplanetary electrons	10 keV-1 MeV	Above polar caps	Solar flare	Synchrotron Cyclotron-resonance Cerenkov	10 kHz-1 MHz
Injun series	Stably trapped	10 keV-5 MeV	Ring current ($L \sim 4$-6)	Substorm	Cyclotron-resonance	10 kHz-100 kHz
OV series	Precipitating particles	eV-keV	Near auroral oval	Quiet and disturbed	Cerenkov Cyclotron-resonance	10 kHz-1 MHz

possibly other cases it may be necessary to limit calculations to those frequencies where the radiation theory is well understood or to extend present theory to cover these cases.

Although identifying the particular particles responsible for radio noise observed on satellites is a complex task, the potential payoff in terms of increased knowledge of the magnetosphere is great. In particular, satellite particle detectors make point measurements whereas radio measurements reflect the integrated effects of large numbers of particles. Since radio measurements represent integrated effects, they tend to give one a large scale view of magnetospheric processes. When radio measurements are properly understood, comparisons of radio and particle detector measurements would help resolve the present ambiguity between temporal and spatial variations in particle fluxes. Radio observations could also prove useful in monitoring attempts at artificial manipulation of magnetosphere -- e.g., the possible seeding of substorms by cold plasma injection

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Max North

Radio Acoustic Sounding System

Experiments with a Radio Acoustic Sounding System for measurement of atmospheric parameters in the lower atmosphere have continued. The basic system remains unchanged, with a low power 36.8 MHz CW radar and short, high power acoustic pulses at about 85 Hz. New signal processing equipment has been developed from time to time to improve performance and simplify data reduction.

Up to this time the system has been used almost exclusively for temperature measurements. A simple digital frequency counter measures the period of each cycle of the radar doppler shift signal, allowing calculation of the speed of sound and therefore the temperature at each altitude. With the present equipment temperature profiles can often be measured to at least 1500 meters altitude, although the range is reduced considerably during very windy weather. Normal operation provides temperature readings at 50 meter intervals with about 0.2°C resolution. Accuracy is influenced by many factors, including signal to noise ratio, data processing method, and atmospheric conditions. For typical signal levels and good weather, errors should be less than 1°C.

In order to check operation of the system, comparisons have been made with temperature profiles provided by Weather Service Radiosondes and a captive balloon sounder. In most cases the RASS profile has agreed within one or two degrees from about 300 meters up to its maximum range. Below 300 meters complications due to the use of a bistatic radar produce larger errors which have not yet been dealt with satisfactorily.

Measurements of wind and perhaps even turbulence are also thought to be possible with RASS. Experiments along these lines have not yet been performed but are planned for the future.

Carlos Koo

Observations of Helmholtz Waves in the Boundary Layer of the Atmosphere With A Radio Acoustic Sounding System

The superior resolution and the convenience of high speed sampling of the Radio Acoustic Sounding System has led to the investigation of turbulence in the lower atmosphere.

An incremental recorder has been added to the system and a series of data sets has been taken. Each set was approximately 200 soundings over 15 to 20 minutes, with each sounding equally spaced 4 or 5 seconds apart. Then an autocorrelation with respect to time was taken at a fixed height.

It has been observed, on certain days, that the autocorrelation yielded a well defined sinusoidal curve with a period of approximately one minute. This implied that the atmosphere at that height was oscillating at the same frequency. The sinusoidal oscillation began to show at around 300 to 400 meters and disappear at approximately 600 to 800 meters. It is believed that this well-ordered oscillation was shearing-gravitational waves or simply Helmholtz waves.

Plans have been made, with assistance from the Meteorology Department of California State University, San Jose, to simultaneously record the temperature profile and mean wind velocity profile with the RASS soundings. From the temperature and mean wind velocity measurements, the Richardson numbers can be calculated at different heights. A correlation of the Richardson numbers and the observed Helmholtz waves will be attempted.

V. W. Ramsey

A Feasibility Study For Acoustic Detection of Small-Aircraft Vortices

Having developed a mathematical model for the interaction of a sound wave with the turbulent microstructure of an aircraft trailing vortex, a small-scale experimental effort was initiated to determine the feasibility of using this model to study characteristics of the vortices shed by small aircraft. Although the ultimate value of the model would lie in its application to the study of the more hazardous vortices shed by larger aircraft, the only data currently available for judging the validity of the model are the small-aircraft vortex profiles obtained by H. E. Sherrieb in 1967 at the Pennsylvania State University (M.S. thesis, Department of Aerospace Engineering).

For mathematical validity of the scattering model, vortices in the size range shed by small aircraft (2000-3000 pound gross weight category) would have to be illuminated at an acoustic frequency of at least about 10 kilohertz. Atmospheric path attenuation, on the other hand, establishes a maximum usable frequency of about this same value. Measurements were therefore performed to ascertain system requirements for an acoustic vortex sounder operating at this frequency.

Sensitivity measurements were made to compare the relative virtues of a low-cost dynamic microphone and horn-loaded loudspeaker drivers acting as receiving transducers. Radiation efficiency measurements on the horn-loaded drivers and a direct-radiator tweeter gave comparative data for potential transmitting elements. The upper-end 3dB points for these transducers were as follows:

Microphone	11 kHz	(measured)
Horns	12 kHz	(published)
Tweeter	20 kHz	(published)

For signal-to-noise comparisons, the ambient site noise level was measured using a simple filter-preamp having a 3 dB passband from 3 kHz to 30 kHz. The measured site noise was 20 dB above the internal preamp noise, so preamp noise did not seriously affect the data.

The results of the tests showed the microphone to be far superior (at least at 10 kHz) as a receiving transducer -- its sensitivity surpassing that of the loudspeakers by a full 10 dB. The transmitting efficiencies were of the following orders of magnitude:

Element	Frequency (kHz)	Efficiency (percent)
Horns	1	1
	10	0.01
Tweeter	10	0.01

The above data were used along with scattering cross sections calculated from the theoretical model to determine maximum permissible receiver-transmitter separations -- and hence maximum permissible flight altitudes -- for obtaining soundings from the vortices of a small airplane (scattering from mechanical turbulence demands a bistatic radar configuration). As an example of a sounder which could be built using, for the most part, currently available equipment, system calculations were performed for four- and six-microphone receiving arrays used in conjunction with a ten-horn transmitting array, each horn being driven by 12 watts of in-phase or real power.

The results were that for a 20 dB signal-to-noise ratio at the receiving array output terminals, the antenna separations could not exceed about 200

feet, and the airplane could not fly higher than about 200 feet. It would be almost imperative that such low-level flight be conducted at an airport. Furthermore, the airspeeds required to duplicate the vortices measured by Sherrieb are about 50 percent higher than the takeoff and landing speeds for that size aircraft. Hence the required fly-bys would have to be worked in on a traffic-permitting basis at the airport. Needless to say, the net amount of flying time required for collecting an adequate set of data could be quite expensive.

In conclusion, it was shown that acoustic soundings of even small vortices should be possible with ordinary equipment. However, in order to duplicate the flight conditions under which the vortices measured by Sherrieb were generated, private runway facilities would be almost imperative in order to keep airplane rental expenditures within reason. The idea of making such acoustic measurements has, therefore, been temporarily set aside.

An interim report on the theoretical scattering solution is in the final stages of preparation.

Calvin C. Teague

Bragg Scatter Probing of Sea State

Two major experiments were performed during this period: one in Hawaii during September, and one on Wake Island during November. Each will be described in turn. Both experiments used LORAN-A signals and utilized the Scripps pitch-and-roll buoy for surface truth calibration.

As a result of the difficulties encountered in interpreting the data from the Hawaii experiment in September, 1971, it was decided to repeat

the basic bistatic geometry experiments in a Trade Winds area in September 1972 with two major changes. First, the receiver was land-based near Hilo, Hawaii and the LORAN-A transmitter at Upolu Point, Hawaii was the primary source of illumination. (Echoes from the Kauai transmitter were also recorded, but these were very weak.) Second, a switched four-beam receiving antenna was used. The antenna consisted of a pair of two-element arrays using loops with quarter-wavelength spacing. The phasing lines could be switched, and the arrays were selected so that the main lobe of the beam could be steered to one of four different directions. Data were recorded with time-interleaved samples from all four antenna directions, so that four simultaneous measurements were made. The resulting observations yield four equations in four unknowns for each delay-Doppler pair; these can be solved very simply compared to the inversion of a large matrix as previously attempted. (A very small region in K-space remains where the equations become singular; the area of this region was minimized by the proper choice of the angle between the two pairs of loops, as determined by a computer analysis of the geometry.) This experiment eliminated the two major problems encountered in the previous Hawaii experiment: the receiver had no velocity relative to the transmitter and the simultaneous observations in four directions eliminated the effects of nonstationarity.

To ensure maximum accuracy, both the receive antennas and the LORAN signal strength were calibrated. The antenna arrays were calibrated by carrying a low-power beacon around a 3-km arc on board the RV Holokai. Range and position of the ship were determined using the ship's radar and an optical transit at the receiver site. The illumination of the ocean by both LORAN transmitters was measured at the ocean surface along a

zig-zag course from Makapuu Point, Oahu, to Hilo, Hawaii and in the return direction via a different course. Measurements were made every 15 minutes during the 30-hour journey each way. In addition, a preliminary site survey was conducted during August on the three islands of Oahu, Maui and Hawaii by making direct-signal strength measurements at about 50 locations on the three islands. All of these data will eventually be combined to generate a model for the attenuation and shadowing effects of the islands. The radar data have all been transferred to digital computer tape and are awaiting analysis.

The second major experiment was a land-based, monostatic synthetic aperture experiment on Wake Island in November 1972. Wake Island was chosen because of its location in the Trade Winds region, its small size (maximum dimension 6 km) and isolation from other land masses for hundreds of kilometers, and the existence of both a long runway (3 km) and a LORAN A transmitter on the island. The monostatic geometry implies that echoes will be received only from 7-second ocean waves travelling radially to or from the radar. The ocean directional spectrum of these waves is measured by determining the angle-of-arrival of the echoes, assuming a homogeneous sea. Antenna directivity on the order of 5-10 degrees at a radio wavelength of 154 m is obtained by carrying a simple antenna at a constant velocity along a straight line many wavelengths long. The frequency of the incoming wave is known very accurately from the (single-wavelength) Bragg reflection mechanism and the ocean-wave dispersion relation, and by measurement of the transmitted frequency. In the simplest, unfocussed mode of operation, arrival angle is measured simply by noting the additional angle-dependent Doppler shift induced by the

receiver motion. This angle measurement is unambiguous over a 180° range; the left-right ambiguity is resolved by using a cardiod pattern for the basic antenna, and alternately switching the main lobe to the left and right of the vehicle track while recording samples in a pulse-interleaved fashion, as in the Hawaii experiment. Two main paths were used for the synthetic aperture. One, along the taxiway, was about 2.7 km (17.5 wavelengths) long; the other, nearly orthogonal to the taxiway and along the ramp parking area, was about 1.0 km (6.5 wavelengths) long. A road, with one bend in it, provided a third path about 2.1 km (14.0 wavelengths) long. Some 200 runs were made over an 8-day period.

The experiment has an inherent redundancy because the ocean-wave spectrum for the full 360° can be computed independently from data from approaching waves or receding waves. If all the assumptions are satisfied, the two spectra should differ only by a rotation through 180°. Preliminary data processed so far are very encouraging and indicate that ocean features as narrow as 10° are resolved by this technique.

The weather conditions for the experiments were ideal. At the beginning of the experiment, the wind was about 16 knots, ± 10%, for days at a time. Later on, typhoon Ruby came within about 300 km of Wake Island, and the wind on the island increased to about 25 knots, with gusts to 30 or 35. Significant changes in both the amplitude and the direction of the ocean echoes were noted during this period (the detailed analysis is yet to be done). In addition, with the receiver stationary, during the height of the storm, strong second-order signals were observed for the first time at 2 MHz. These signals were similar to those observed at 30 MHz, but the wind had never been strong enough before this to generate

the second-order signals at LORAN frequencies. The majority of the data processing is yet to be done, but it appears that the Wake Island data represents our best data so far in terms of significant oceanographic measurements.

Don Johnstone

EM Scattering From Ocean Surfaces

The results of radar measurements of the ocean surface in the frequency range of 1 to 30 MHz have not only verified the existance of Bragg scattering, but have also indicated that additional scattering mechanisms are present. The goal of this study is to derive a mathematical description of ocean surface scattering in terms of the directional wave spectra in order to explain and predict the radar results not attributable to simple Bragg scattering. If the scattering model can be made complete enough then it might be possible to model the directional spectra from measured spectra.

Some of the physical phenomena which are thought to be contributors to non Bragg scattering and which should be accounted for in a model are ocean wave-wave interactions, deviations of an actual ocean wave profile from a sinusoid, multiple scattering and second order effects in the EM scattering theory.

At present a scattering model based on Rices' (1951) perturbation approach to scattering from slightly rough surfaces is being developed. One reason for using the Rice approach is that scattering cross-sections (observables) are formulated directly in terms of surface spectra. The cross-section formulations are being extended to include second order terms in the perturbation approach at least for non-conducting time

independent surfaces at non grazing incidence. Future work will include modifying these preliminary results to surface wave scattering on time dependant surfaces.

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Alvin M. Despain

Real Time Fourier Transform System

A study of the feasibility of constructing an inexpensive real time Fourier Transform Display for bistatic radar receivers has been initiated. Such a display would be a valuable aid in conducting bistatic radar scattering experiments especially those that require adjustments either prior to or during the scattering experiment.

The immediate application is to the display of long-period, directional ocean wave-height spectra derived from the bistatic reception of Loran A signals [1,2,3]. The fundamental problem is to Fourier Transform in real time each range bin sample (some 32 in all) of the scattered Loran pulse. Approximately 256 frequency bins are needed for each range bin. It has been decided that any two range bins will be displayed in real time since this will provide sufficient information for real time operation and that extensive post-experiment computer analysis will continue to be employed for data reduction.

The investigation has centered on developing inexpensive digital Fourier Transform techniques. For the low data rates required in the ocean-wave experiments, less circuit complexity is obtained if a Direct Fourier Transform (DFT) is employed instead of the currently popular

Fast Fourier Transform (FFT). Thus each input sample is immediately transformed and added to the display buffer as it is received and no input buffering is required as would be the case for the FFT. This has the added benefit of a display that is updated with every received pulse.

A study of the trade-off of performance vs cost has been completed so that the optimum hardware configuration can be determined for data sample input rates from 1 to 10^{12} samples/second.

The investigation has also resulted in the development of a new digital circuit for hard-wired Fourier Transform systems. The technique applies a modification of the CORDIC [4] technique developed by Volder for rotating vectors to the various Fourier Transform algorithms.

The result is a digital circuit that can transform at about three times the data rate of conventional circuits of about equal complexity yet no function (cosine for example) tables or function generation is needed. This provides a great savings in Fourier Transform systems. The circuit can be implemented in either serial (least expensive) or parallel arithmetic form and can be used with the DFT or the FFT algorithms in single processor, vector or array modes [5].

A design for the ocean-wave experiment is currently being completed. At this time it appears that a very simple yet powerful display system will result from the application of these new techniques.

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M. Sites
K. Chen
J. Vasquez

Development of an Unmanned Geophysical Observatory for use in the Antarctic (NSF-C-582)

The Unmanned Geophysical Observatory (UGO) at McMurdo has now completed more than a year of continuous operation with the INTELSAT system. The returned data shows all systems, including the experiments, the thermal regulator and the propane generator, are performing reliably. Quality of data has been excellent, proving the effectiveness of remote automatic stations for the monitoring of the Earth's environment.

A problem with intermittent telephone line outages has been corrected and the combined error rates for the Antarctic to Jamesburg satellite link and the Jamesburg to Stanford telephone line link are typically below $5x10^{-5}$. The majority of these errors are due to the latter link.

The only malfunctions of the UGO receiver at the Jamesburg earth station has been due to crystal aging of the transmit source, causing the

signal to fall outside the range of receiver lock-in. The problem has been corrected by manually retuning the local oscillators at Jamesburg when it was needed.

The online HP 2115A computer at Stanford which provides real-time monitoring and data-stripping capability has functioned without failure so far.

Spares for the Jamesburg equipment are now at hand. Present work being done includes the redesign of a demodulator for both the Jamesburg and UGO receivers. Plans are also being made for a new data encoder and data decoder for the UGO.

Robert T. P. Wang

Television Video Data Compression Studies

The past 6 months were spent on completing the development of a mathematical model of the television video source designed for application in video data compression algorithum evaluation. This work is documented in a thesis and published as Scientific Report No. 41, Radioscience Laboratory, Stanford Electronics Laboratories, Stanford University, Stanford, California, December 1972. Both are entitled "A Study of the Structure of Television Pictures as Applied to Practical Data Compression Techniques".

The next six months will be spent in further developing the application of this model to other aspects of video data compression, collaborating with NASA-Ames Research Center in developing their hardware Hadamard Transform data compression system and initiating studies on high density

digital recording. Correlative signalling techniques will be studied to achieve higher recording density. Effort will also be expended to publishing papers on the work of the past 6 months and new results obtained in this next half year.

Nirdosh Bhatnagar

Speech Compression

The problem of "Speech Compression" may be treated as a subclass of techniques to compress data efficiently. The importance of economical storage of speech information was recognized a few years ago. Presently, speech analysis and synthesis is done with the aid of computers. The present object of research is to do speech analysis and synthesis in real-time using the existing LSI technology.

A simple and useful model of speech waveform consists of the convolution of three components, representing pitch, the shape of the vocal cord or glottal excitation, and the configuration of the vocal trait.

Over a short-time interval, the speech waveform looks like a segment of a periodic waveform. This periodicity is a direct consequence of pulsating airflow through the glottis. The duration of a pitch cycle always varies somewhat from one period to the next.

We need to determine if a particular speech segment is voiced or unvoiced. If it is voiced, we need to know its pitch. This can be done essentially by three techniques 1) Auto correlation 2) Cepstrol and 3) Inverse filter analysis (the SIFT Algorithm).

Presently interest is focussed on realization of special purpose hardware, so that pitch entraction could be done in real-time.

Eduardo W. Bergamini

Incremental Computation

Our recent work has consisted in organizing procedures that can be applied in the digital simulation of simple, linear system models of first and second order. The results of such simulations are expected to give valuable information for the simulation of higher order systems. It is meant by higher order systems, in this case, those that can be realized by a cascade and/or parallel connection of the referred first and second order blocks.

The procedures for simulation are software versions of digital differential analyzers (dda's). Based on the results obtained in future simulations, it is expected that conclusions will be drawn concerning those dda's configurations that are more suitable for hardware realizations, eventually, large scale integration.

A non-linear case (Van der Pol equation) has been under consideration for software realization of the proposed dda structures under more stringent performance requirements, as far as integration is concerned.

More extensive analyses of previous data obtained with software simulation of the harmonic equation ($\ddot{y}+y=0$) have brought to light new, consistent behavior of performance of the dda structures under consideration.

Joost Mortelmans

An Adaptive Processor

A new processor architecture was defined which in a limited way has the ability of adopting its parallel subprocessor configuration to the problem programs at hand i.e., the amount of parallelism can be exchanged for increased performance. The hardware and the instruction sets of the different configurations were defined. Special hardware aids were designed to facilitate the data communication between the parallel subprocessors and their relative merits were discussed.

The first of several applications to be analyzed was matrix multiplication. The dimensions of the matrices involved are important in choosing the best storage method (reducing the amount of unusable memory locations). For each method described an expression is given stating the amount of storage needed. Finally a table was obtained indicating the storage requirement in function of the dimensions of the matrices and also showing which storage method is more economical in each case.

Dan Allan

Satellite Communications for Alaska

The first phase of this project is nearing completion. It summarizes the engineering experiments undertaken over the past year, using ATS-1: teletype, simplex and duplex voice, xerox facsimile, photo-facsimile, and slow-scan TV. Stanford, University of Washington, University of Wisconsin, and University of Alaska are among the participants. This summary comprises a final report for the first phase.

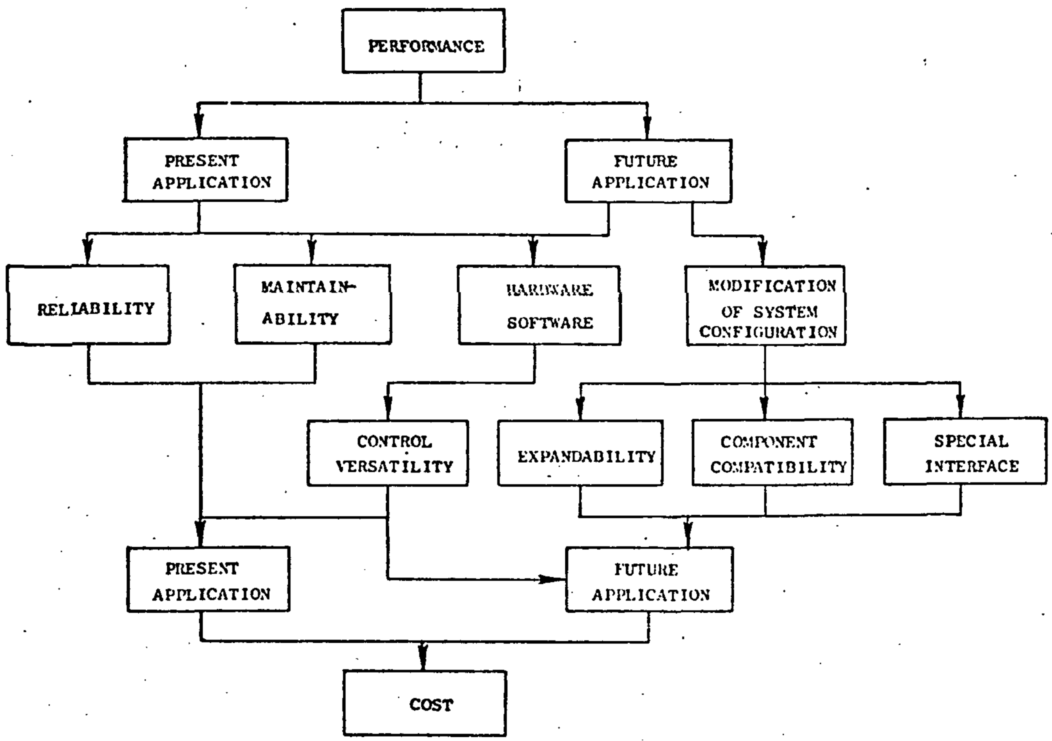
The second phase examines near-future satellite communications technology as it might be used in Alaska: future satellites (such as ATS-F, Telsat, or several of the proposed U.S. "domestic satellites"); small ground stations; terminals; program scheduling and content; and the social impact of such systems upon Alaskan natives. For this second phase, I am mainly involved with computerizing minimum-cost system designs.

<u>The Synchronous Orbit: Optimal Packing, and a Shadow-Cost Value</u>

As part of a NASA teleconferencing study, frequency-space utilization is being examined as it pertains to Synchronous Satellites. The work I am pursuing extends previous work and incorporates recent results (such as sidelobe suppression for small-diameter ground antennas). Technical factors include interference margin modulation multiple access and ground antenna directivity. Economic factors include cost of antennas as a function of their directivity and the cost of alternate terrestrial communications options. A dollar value per unit of electro space (bps per degree of orbital arc per Hz) will be deduced from the analysis, and various management alternatives will be assessed.

Data-Acquisition Systems (DASs)

The purpose of my present research is to find a configuration - independent tool to allow the performance/cost analysis of DASs as well as a prediction of their behavior.



COST VS PERFORMANCE IN A DATA ACQUISITION SYSTEM

SU-SEL-72-028

With the block diagram presented above as the foundation, the following steps will be carried out:

1. Determine essential (primary) and non-essential (or less-essential or secondary) parameters of a DAS.

2. Establish criteria for cost and performance (as a function of reliability, flexibility, maintainability, which in turn are subfunctions of some or all of the parameters determined in (1)).

3. Develop a general applied methodology for

   a. calculating both cost and performance

   b. developing cost/performance trade-offs

   c. optimizing cost/performance ratio

This mathematical tool should then allow one to:

1. Determine the configuration of the units which optimize cost/performance (according to set of specifications), or

2. Study the performance of systems already built.

W. Carl Mitchell

Terrestrial Telephony Transmission Costs

Consonant with my research aim to define the major parameters of and construct a model for telecommunications planning in developing countries, a cooperative effort was undertaken with Pacific Telephone and Telegraph Company to determine the least-cost terrestrial facility for telephony links of a given length and expected yearly growth. The study, completed in November, 1972, produced a set of computer programs that has been called, Facility Planning Program Package. Using this package, it is possible to compare the costs, year-by-year or discounted to year zero, of providing service with any one or all of the presently used Bell facilities -- i.e., physical cable-pairs (19 or 22 gauge), N2 and N3 analog carrier systems, T-carrier systems, and microwave radio carrier systems.

Partial results from program runs are indicated in figure 1. This figure shows the least-cost facility corresponding to an initial demand of 0 circuits, a yearly increase in demand of YID circuits, and a link-length of M miles.

Present effort has now been focused on producing a somewhat similar model for providing the same service (restricted to small values of YID) by satellite and accompanying earth stations. The completed study is expected to be of considerable value to developing nations (or any area where telephone and television service may yet be in their infancy) in assessing the relative merits of a national satellite system.

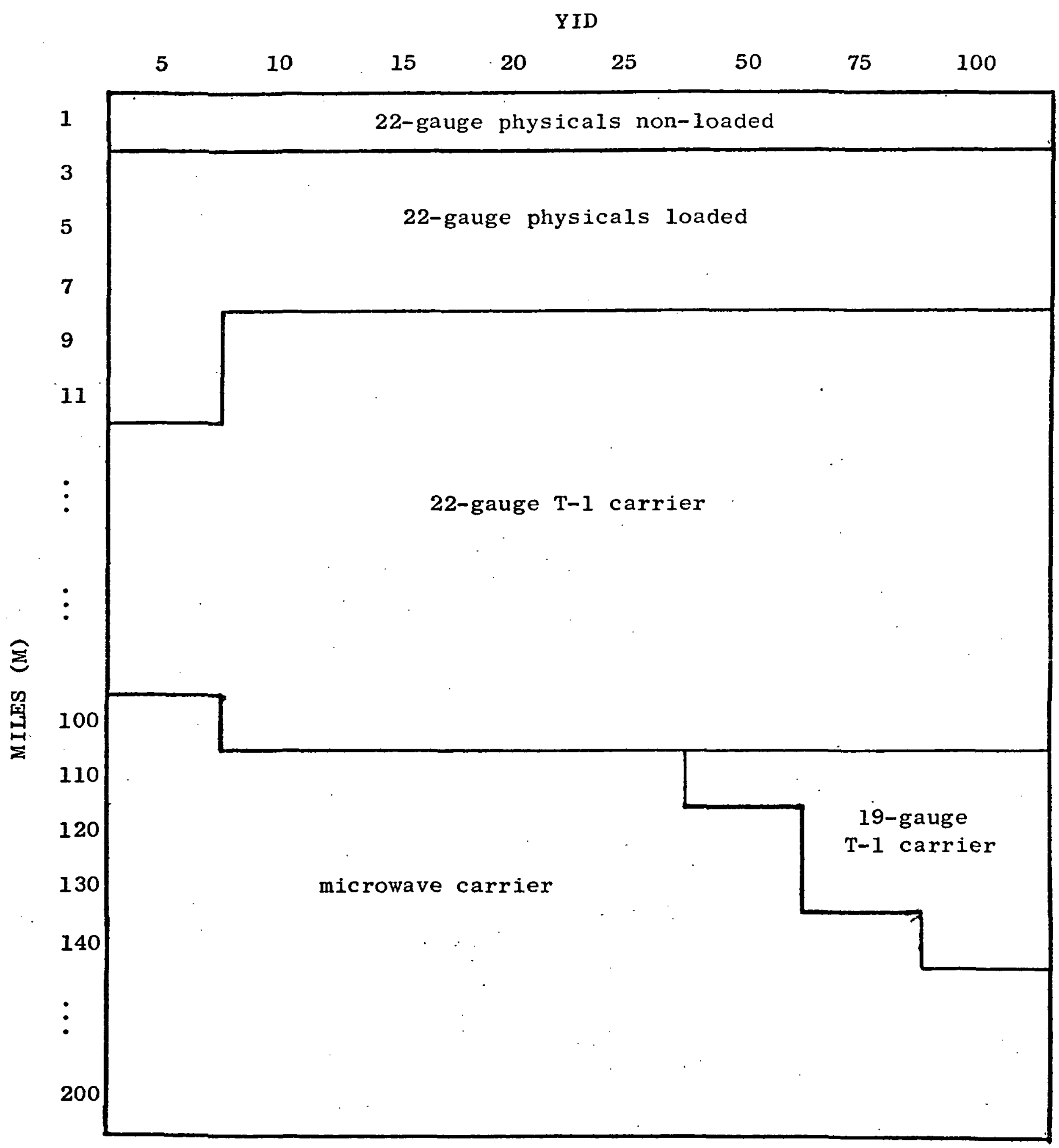


Figure 1. The least-cost terrestrial facility for telecommunications links of M miles and YID yearly increase in circuit demand.

V. Mani

Digital Speech Processing

Digital Signal processing techniques are becoming increasingly important in Speech Analysis and Synthesis. The advantages of digital speech analysis systems are multifold, the important ones being

1. It is possible to realize very complex and flexible analysis and Synthesis Systems and thus obtain very good representations of the Speech Signal.

2. Digital Systems can be designed so that they are highly reliable, stable and low in power consumption.

3. Very efficient (in terms of hardware) realisations can be designed because it is relatively easy to multiplex digital hardware.

The techniques involving transmission or storage of speech include design of digital filter bank spectrum analyzers, homomorphic analyzers of speech, predichue coding and hardware realizations of a digital formant synthesizer. Although spectral analysis is a well known technique for studying signals, its application to speech signals suffers from a number of serious limitations arising from the new stationary as well as the quasi periodic properties of the speech wave. Representation of the speech signal in terms of predictor coefficients is an attractive idea. In fact, it has been reported that efficient representation could be possible with a data rate of 2400 bits/sec compared to 70,000 bits/sec in direct PCM encoding. Computationally this predictive technique takes about 25 times real-time for both analysis and synthesis on a GE635 digital computer. A study has been undertaken to explore the possibilities of representing the data with fewer bits/sec (which is a very real probelm in terms of storage) and to improve the computational speed. The feasibility of an economical and fast hardware speech synthesizer is also being studied.

Section B

Recent Publications

Craig, I. J. D., J. L. Culhane, K. J. Phillips and J. F. Vesecky, Further Results on Cooling Mechanisms for Soft X-Ray Flares, submitted to SOLAR PHYSICS

Croft, T. A., Traveling Regions of High Density Observed in the Solar Wind on August 3 and 9, 1972, J. GEOPHYS. RES., in press.

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Section C

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